PHENIX

STAR

# A Fast, Compact TPC for PHENIX and STAR with Enhanced Electron ID Capabilities

Craig Woody
BNL

RHIC Detector Workshop
Gas Detector Working Group
November 14, 2001

# A Fast, Compact TPC for PHENIX and STAR With Enhanced Electron ID Capabilities

A fast, compact TPC would serve as a multipurpose tracking detector in the central region of both PHENIX and STAR and would provide electron identification for low momentum electrons by dE/dx. It's electron id capabilities could be extended by incorporating a photocathode layer on the outer surface of the TPC which could serve as a Cherenkov detector for detecting electrons that would have a minimum sensitivity to hadrons (i.e., also serving as a Hadron Blind Detector).

## The physics topics addressed by this detector are:

- Low mass electron pairs

  Tracking and electron id of low momentum electrons provides Dalitz rejection to measure low mass electron pairs, $\rho$ , $\omega$ , $\phi$ , etc.

- Jet physics

  An inner tracker covering $2\pi$ in azimuth, $|\eta| \sim 0.75$, and $\sim 20<R<60$ cm allows jet measurements in both heavy ion and pp collisions

  (e.g., for studying away side jets tagged by $\gamma$s or high $p_T$ leptons)

- Charm and B decays

  Combined with a high resolution inner silicon detector, the tracking capabilities help to resolve secondary displaced verticies from charm and B-decays (also for strangeness: $\Lambda^0$, $\Xi^0$, $K^0$, ... )

- Low $p_T$ physics

  Combined with operating PHENIX with different inner B-field configurations, provides improved momentum resolution and added tracking capabilities, including low $p_T$ (< 200 MeV/c) charged particles.

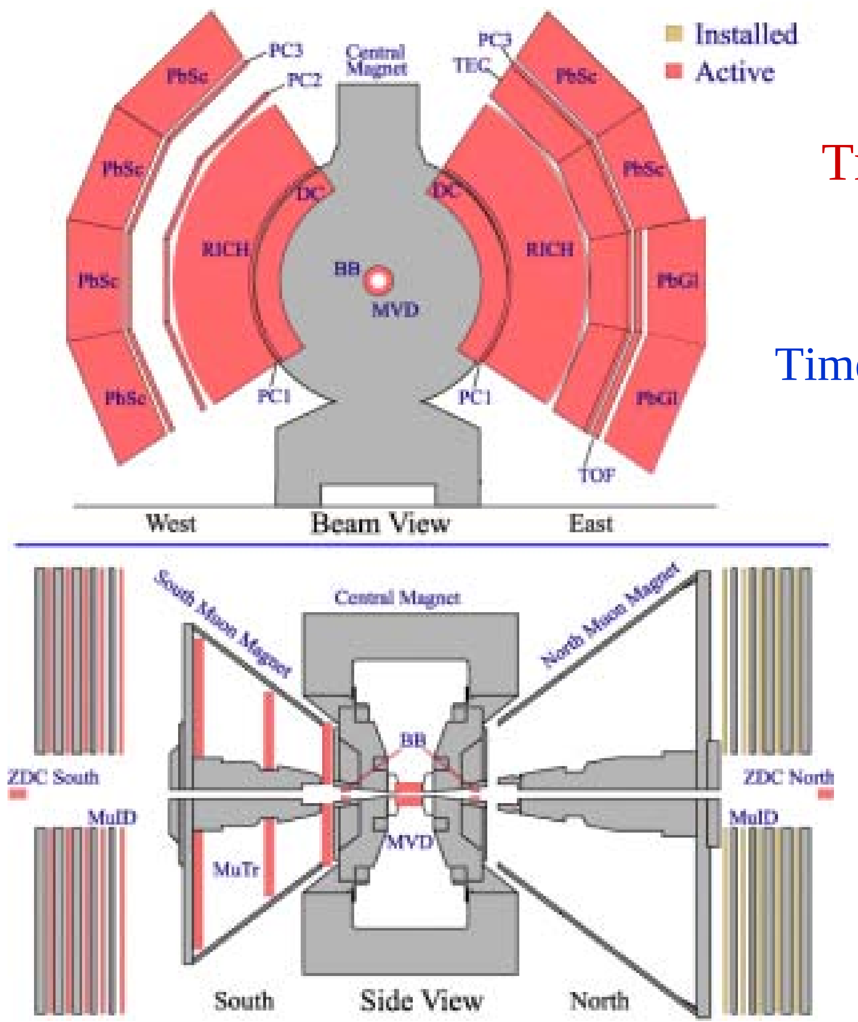
# PHENIX Detector for Current Physics Run

## Electron ID Detectors

EMCAL (PbSc + PbGl)
RICH
TEC->TRD

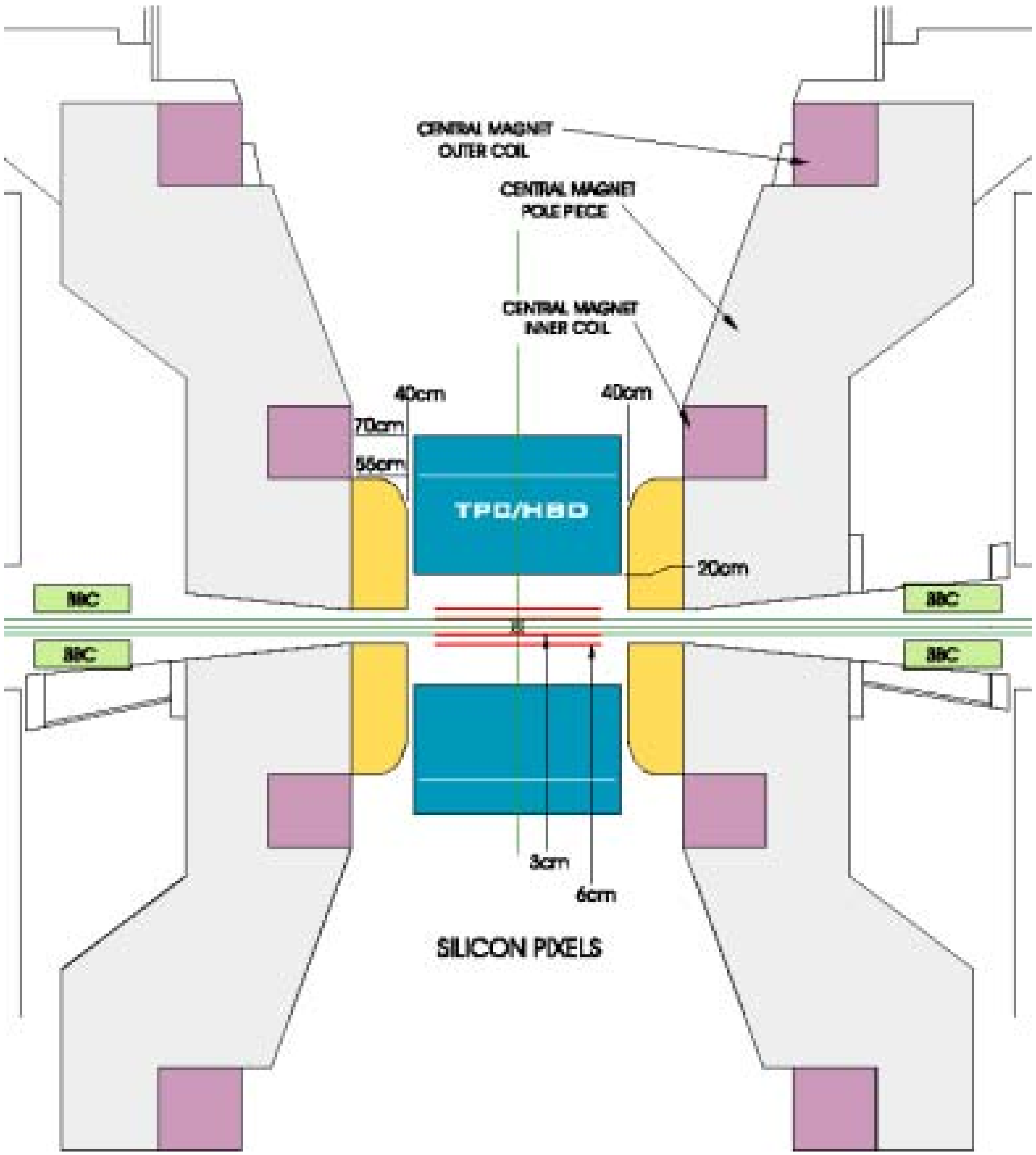
## Tracking Detectors

Drift Chamber
Pad Chambers
Time Expansion Chamber

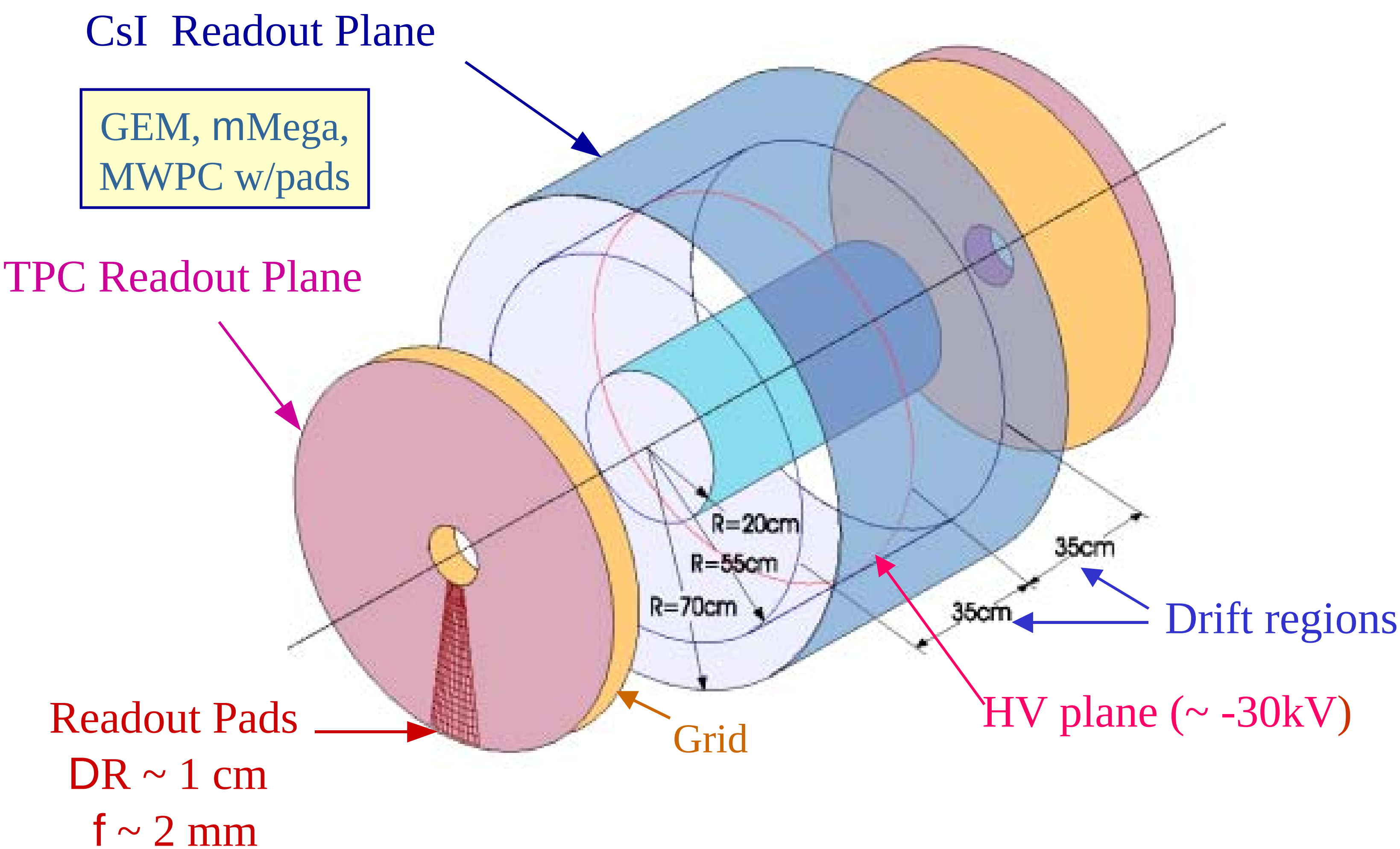



South Muon Spectrometer

North Muon Spectrometer (to be installed in 2002)


CENTRAL MAGNET
OUTER COIL
CENTRAL MAGNET
POLE PIECE
CENTRAL MAGNET
INNER COIL
40cm
40cm
70cm
55cm
TPC/HBD
20cm
BBC
BBC
BBC
BBC
3cm
6cm
SILICON PIXELS

# TPC/HBD Schematic Drawing



# Detector Requirements

- Must have short drift time to work at the highest luminosities planned for RHIC

- Require sufficient two track resolution to handle high track densities and possible space charge limitations

- Must have sufficient charge deposition and sampling to do good dE/dx measurement for electron id below 200 MeV

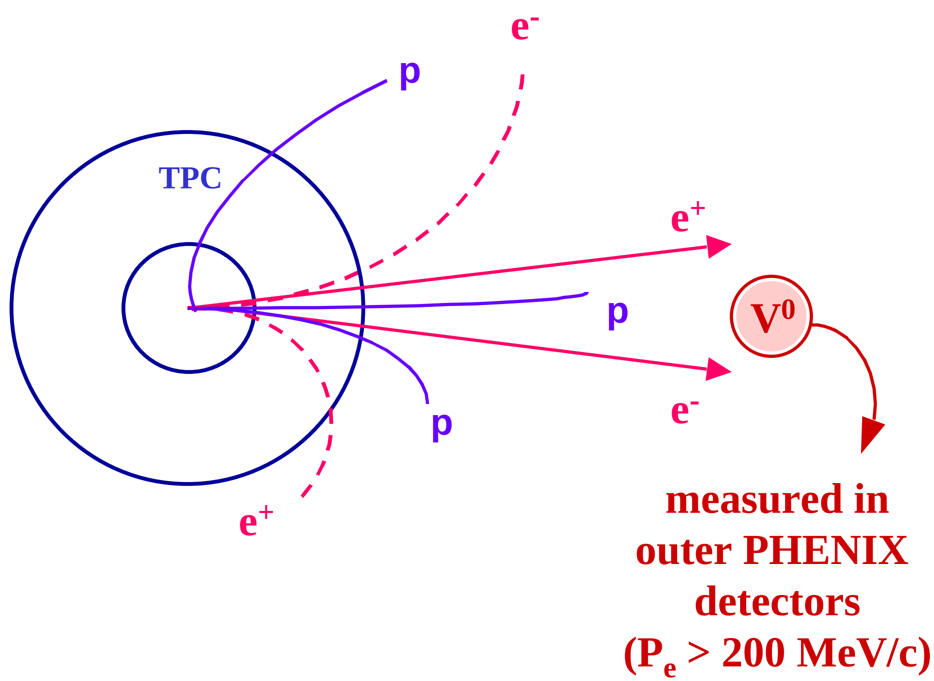
- Adding CsI photocathode layer provides additional independent electron id

- Should have minimal material to minimize conversions and multiple scattering for outer detectors (< 0.1 - 0.2% $X_0$ )

- Must keep the number of readout channels to a "reasonable" number (~ 50-100K, but must also implement zero suppression at an early stage in the readout)

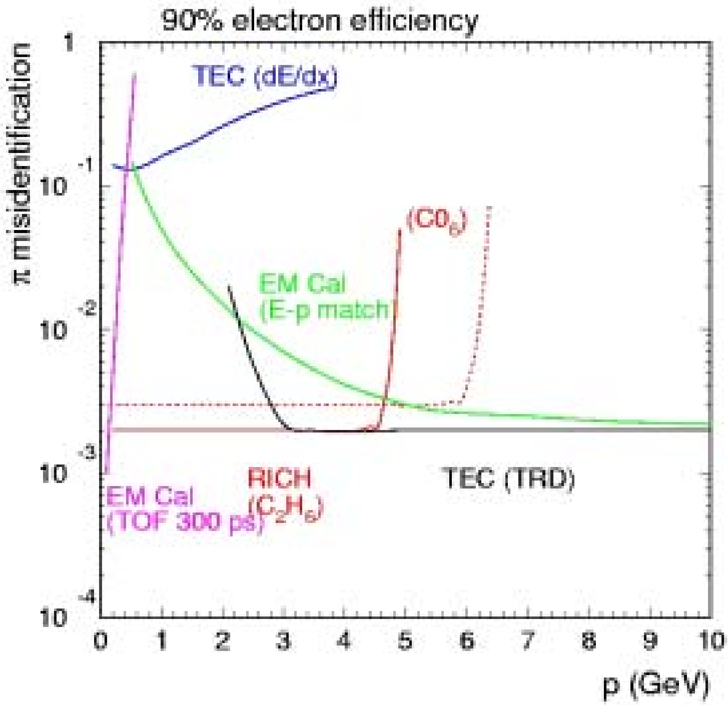
## Using the TPC to measure Low Mass Lepton Pairs and Vector Mesons in PHENIX

- Operate PHENIX with low inner B field to optimize measurement of low momentum tracks
- Identify signal electrons (r,w,f, …) and background electrons with p>200 MeV in outer PHENIX detectors
- Identify low momentum electrons (p<200 MeV) using dE/dx from TPC and/or Cherenkov light in HBD
- Calculate effective mass between all opposite sign tracks identified as electrons ($e_{electron} > 0.9$, $p_{rej} > 1:200$)
- Reject pair if mass < 140 MeV

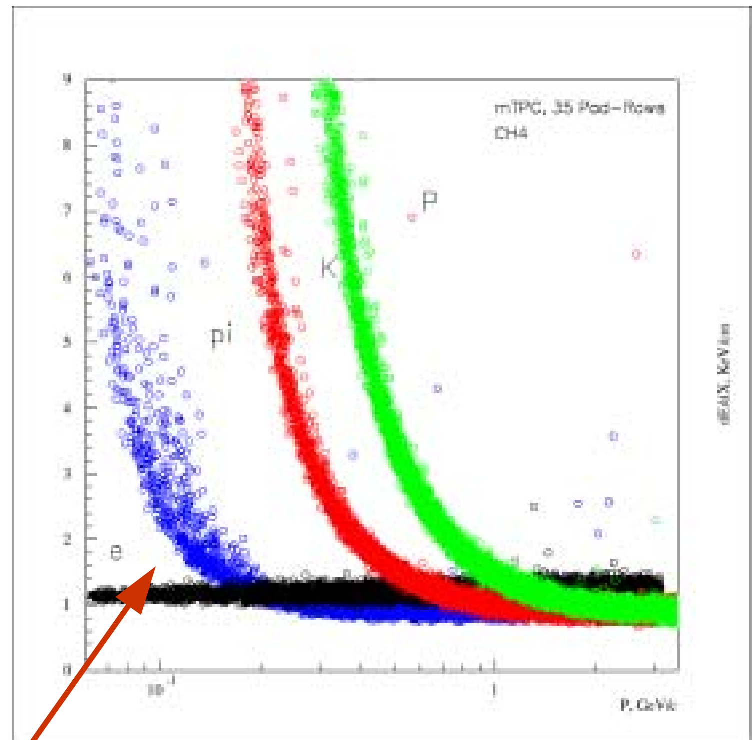



**Must provide sufficient Dalitz rejection (>90%) while preserving the true signal**

# Electron ID in PHENIX



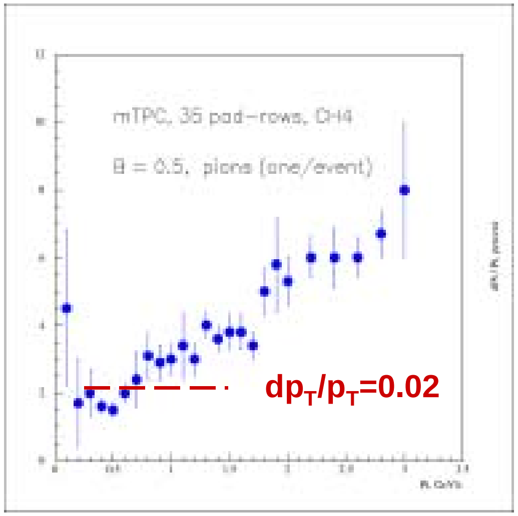

Electron ID provided by outer PHENIX detectors




Electron ID provided dE/dx in TPC
(Simulation by N. Smirnoff)

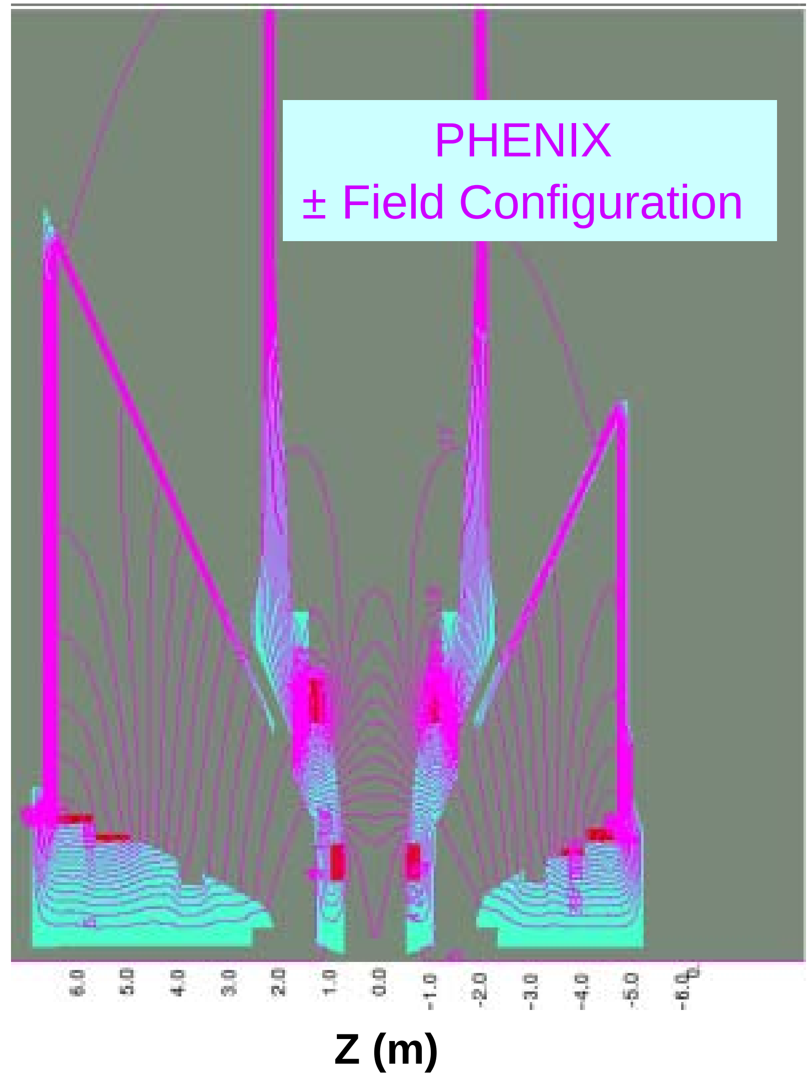
For p < 200 MeV, need
$e_{electron} > 0.9$
$p_{rej} > 1:200$

# Tracking in the Central Region in PHENIX

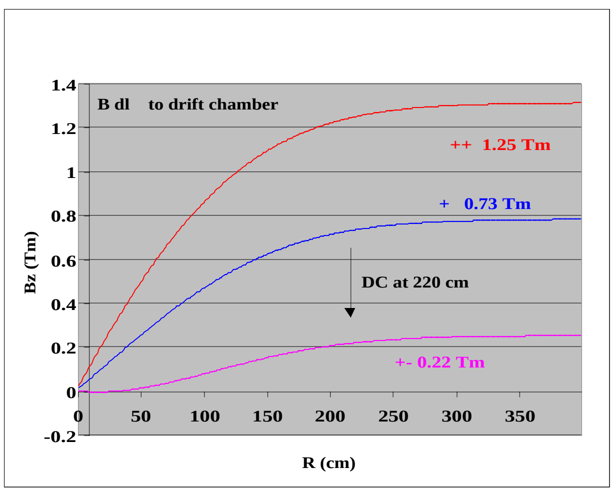



**Momentum resolution in TPC**
300 mm single point resolution in x,y,z

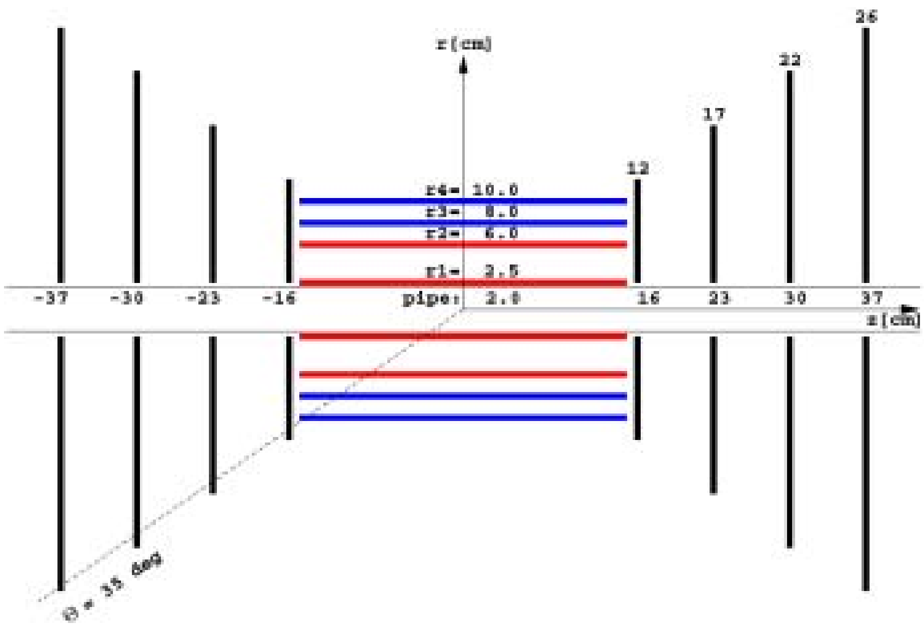
(Simulation by N. Smirnoff)




Field Integral

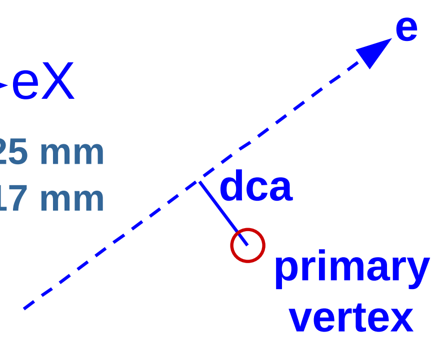


# Proposed Silicon Tracker in PHENIX




D→eX

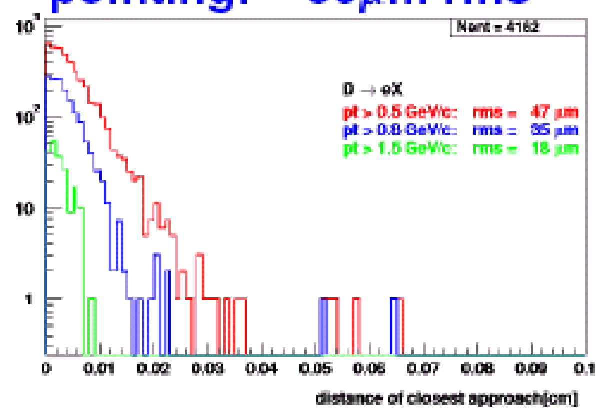
$c\tau_0$ = 125 mm
$c\tau_\pm$ = 317 mm




Pixel barrels (50 mm x 425 mm)
Strip barrels (100 mm x 5 cm)
Pixel disks (50 mm x 200 mm)

1.0% $X_0$ per layer

pointing: ≈ 35μm rms




Simulation by J. Heuser (PHENIX)

# What are the goals and topics for R&D ?

Goals
- Develop a fast, compact TPC for use in high luminosity heavy ion and pp physics at RHIC.
- Determine whether the features of a HBD can be incorporated into the TPC in order to enhance its electron id capabilities.

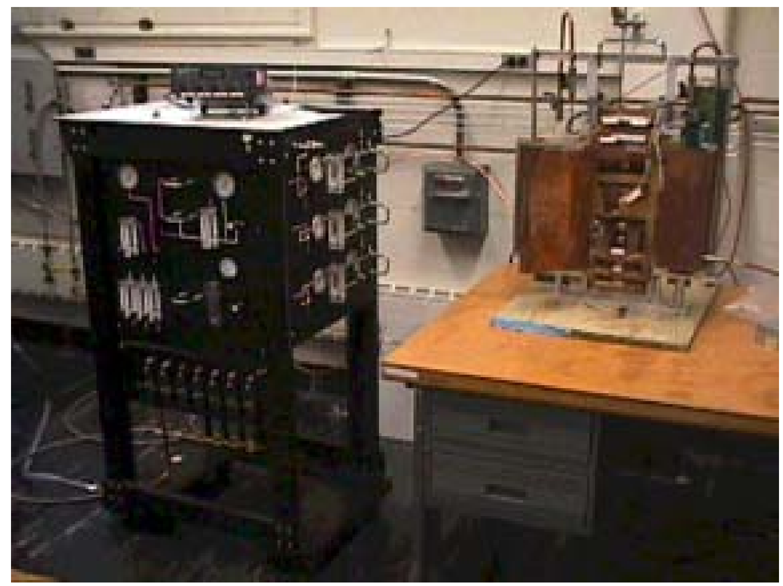
Topics
- Study the use of fast drift gases in the TPC (electronic & optical properties)
- Detector design (field cage, readout plane, construct prototype)
- Investigate readout detector options (GEM, mMega, MWPC w/pads)
- Design of integrated readout electronics
- Monte Carlo simulation studies

## Studies on the Use of Fast Drift Gases

- $CF_4$, $CH_4$, $C_2H_2$ + mixtures
- Measure drift velocities, drift lengths, diffusion parameters, dE/dx, etc.
- Measure optical transmission (extending down into the VUV)
- Correlate optical measurements with drift measurements to study the effect of impurities on drift and transmission properties
- Measurement of scintillation light (l and decay time)
- Study the behavior of these gases in micropattern detectors (GEMs, Micromegas, etc)

# STAR TPC Test Setup
Physics 2-106

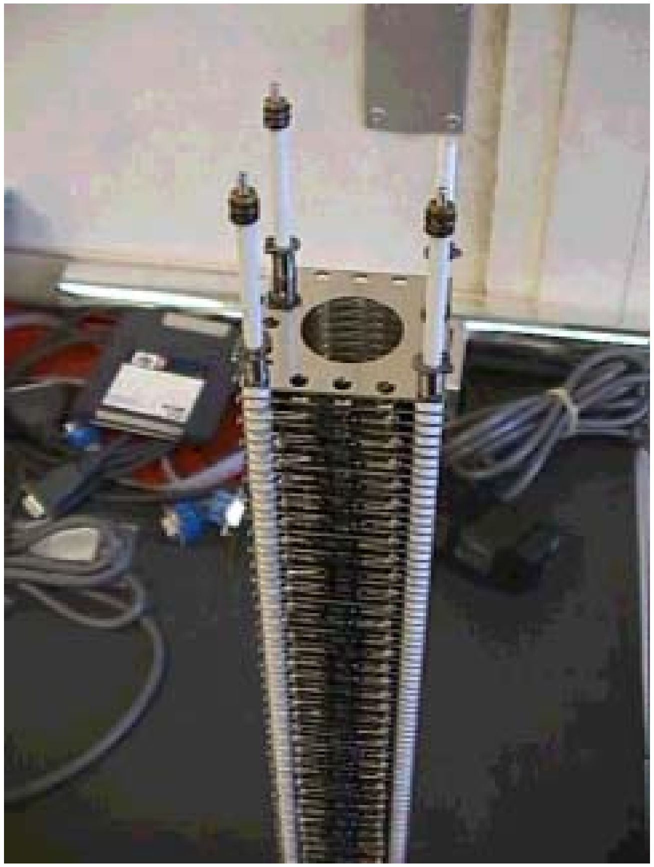
**STAR TPC "Canary Chamber" and gas system**



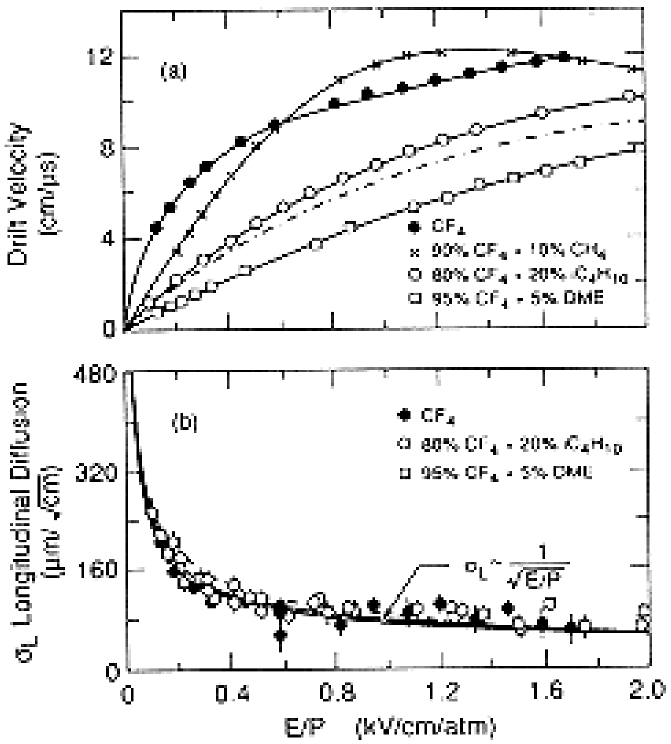
**Measure drift properties of gases**

- Drift velocities
- Drift lengths
- Diffusion parameters
- Ionization energy loss (dE/dx)
- Study impurities
- Study various types of readout detectors

TPC Drift Cell will be constructed to study drift properties of various gases

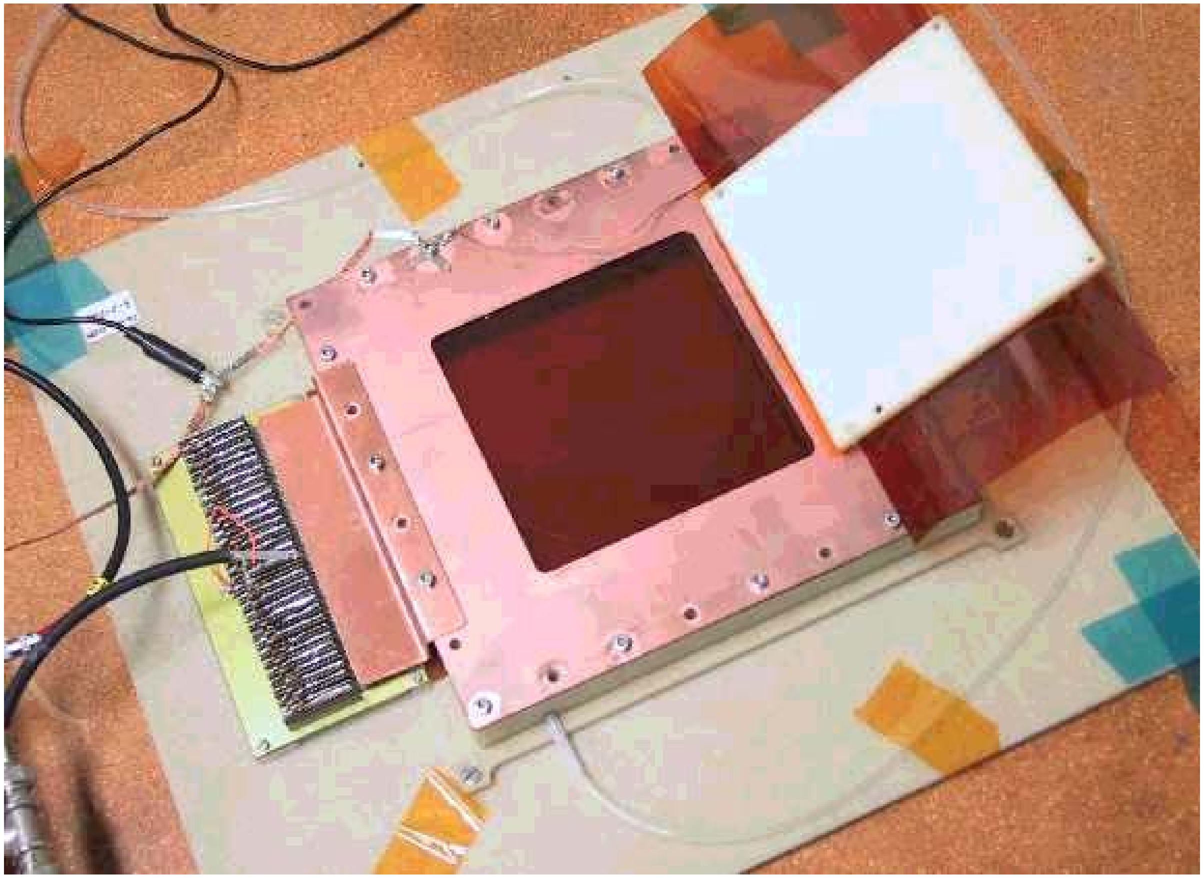


LEGS TPC Drift Cell




J.Va'vra et.al., NIM A324 (1993) 113-126

# GEM Detector
Courtesy of F. Sauli (CERN)

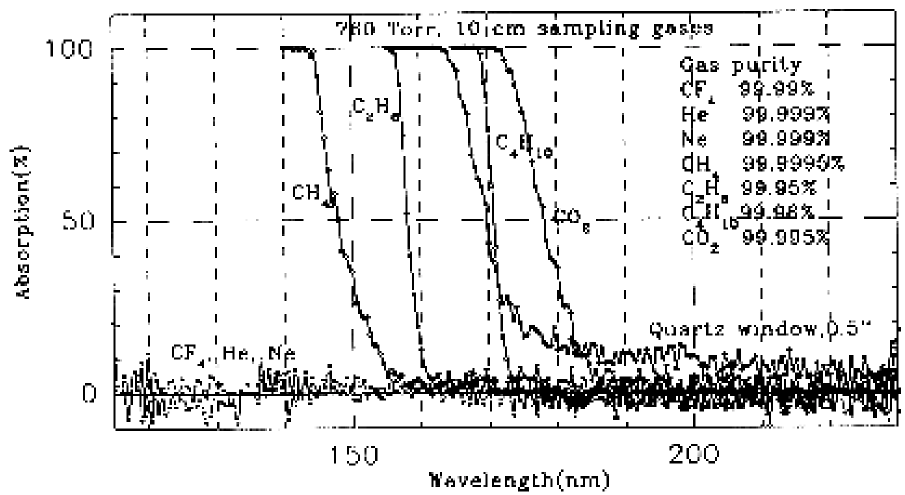


Additional GEM foils will be used to construct readout detector for TPC Drift Cell

# VUV Spectrometer

Measures optical transmission down to 120 nm

Correlate with drift measurements

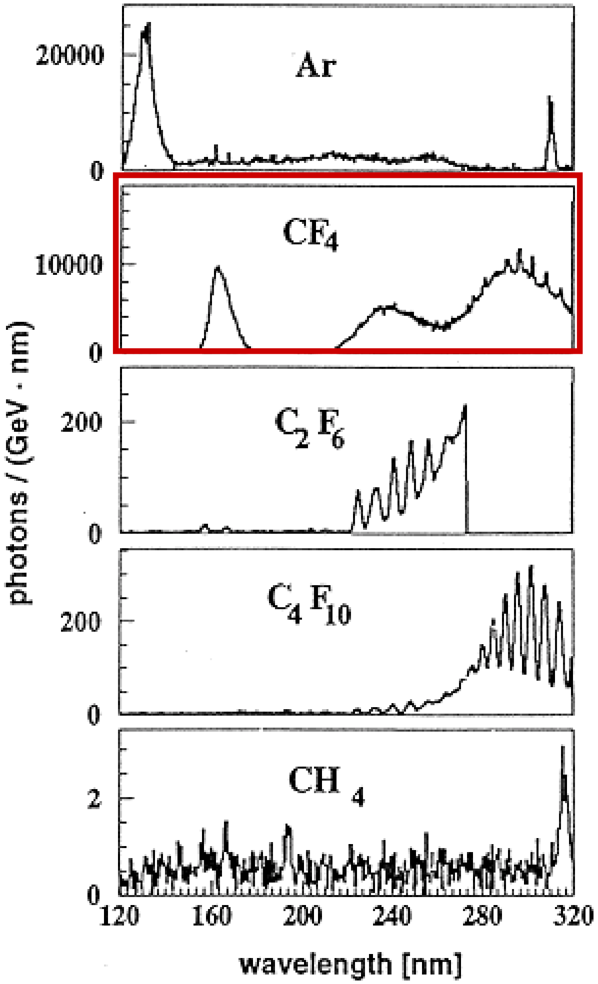



C.Lu & K.T. McDonald, NIM A343(1994) 135-151.

# $CF_4$ Scintillation

Scintillation in the VUV (160 nm)

Measure scintillation decay time




R.Gernhauser et.al., NIM A371 (1996) 300-304.

# Monte Carlo Simulations

- Detailed TPC/HBD detector Monte Carlo already exists which is being used to optimize geometry, pad size, etc (N. Smirnoff)
  - study two track resolution, multihit resolution, diffusion limits, etc.
  - will also run GARFIELD to study field cage configurations

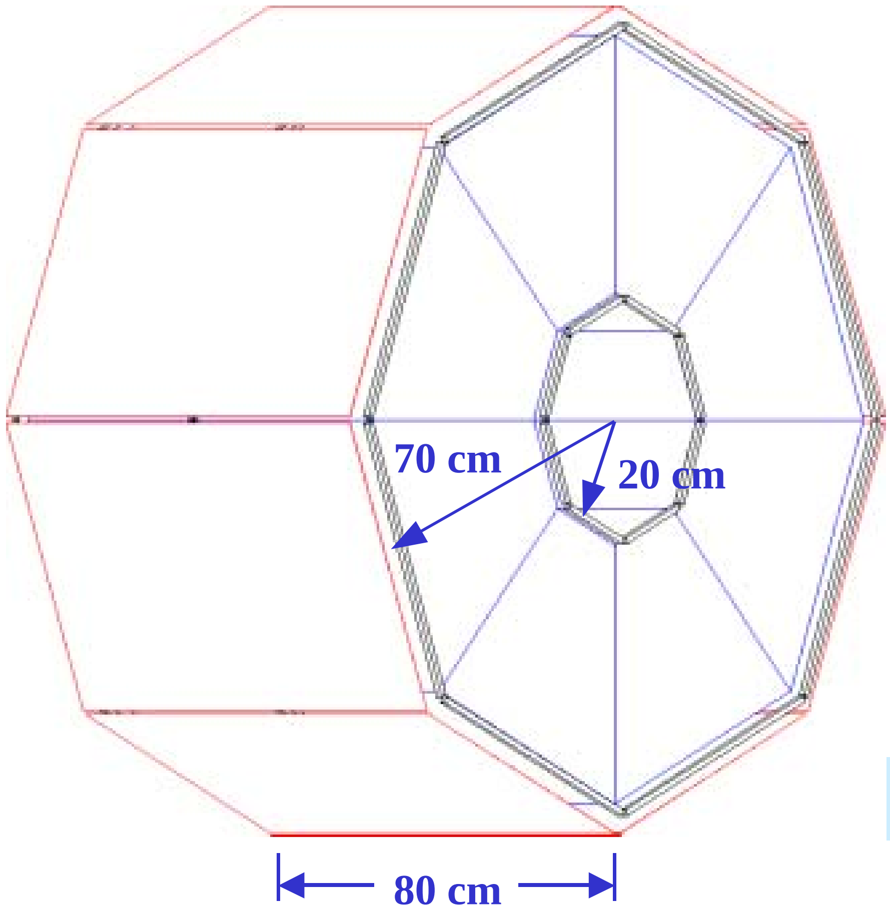
- TPC/HBD geometry is now in full PHENIX simulation package PISA (C. Aidala)

  Note: New proposed silicon pixel detectors have also been added to PISA;
  will use this together with TPC/HBD to study the effect on tracking and momentum resolution

- Studies are currently under way of to study electron pair signals (e.g., r,w,f, low mass pairs) in heavy ion events using EXODUS Monte Carlo (K. Ozawa)

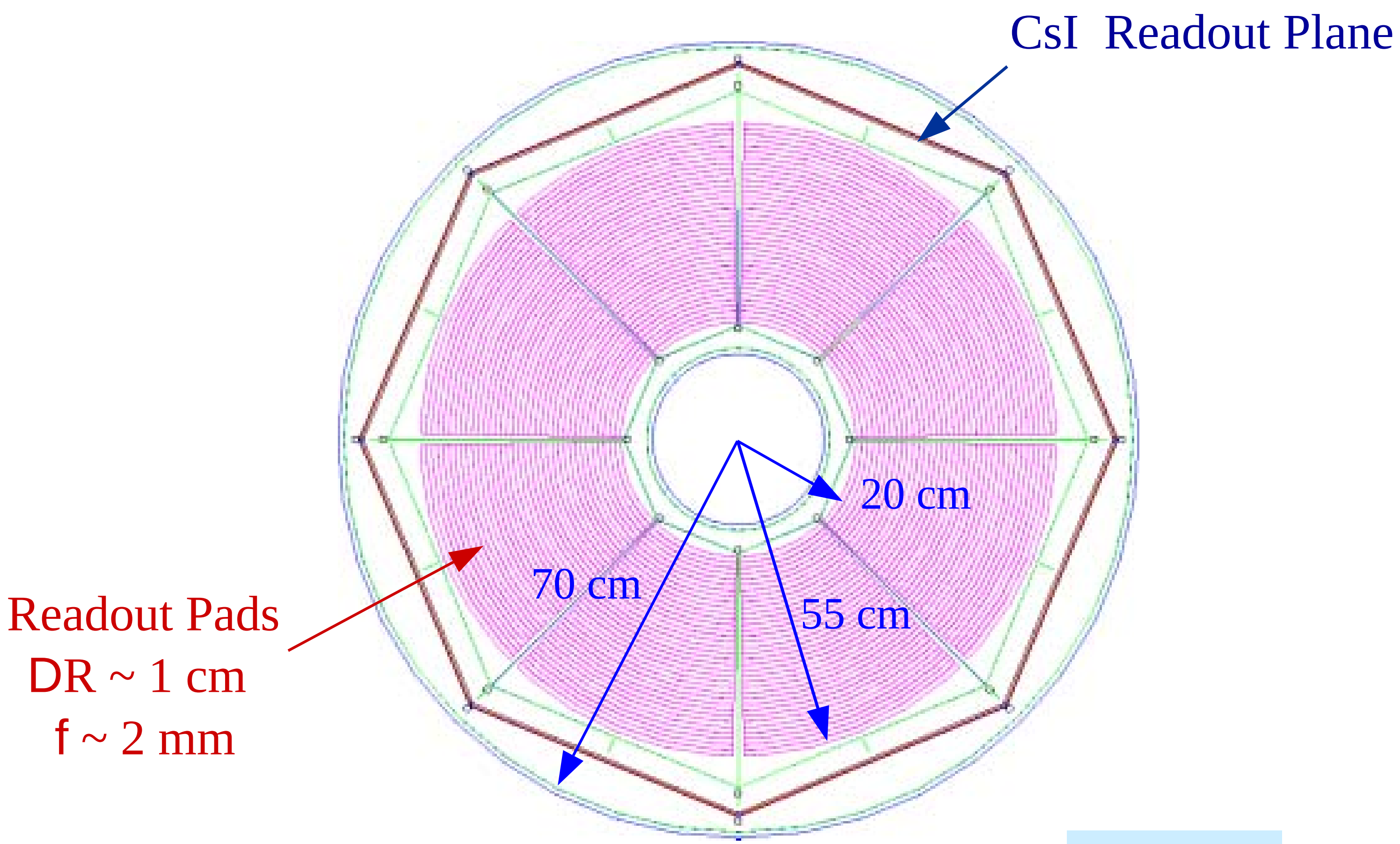
- Next step will be to incorporate all three Monte Carlos programs together into PISA to do full event simulation of electron pair signals, Dalitz pairs, conversions and other background sources, combined with studies of tracking and momentum resolution, using the full PHENIX detector simulation package.

# TPC/HBD Detector in PISA




C.Aidala

# TPC Detector with HBD Radiator




C.Aidala

## Parameters for Heavy Ion Collisions

| Scheme | | RDM | RDM+ | RHIC II |
|---|---|---|---|---|
| Initial Emittance (95%), $\epsilon$ | $[\pi\mu m]$ | 15 | 15 | 15 |
| Final Emittance (95%), $\epsilon$ | $[\pi\mu m]$ | 40 | 40 | $< 6^{*}$ |
| IP beta function, $\beta^{*}$ | [m] | 2.0 | 1.0 | $1.0 \rightarrow 0.5$ |
| Number of bunches, $M$ | | 60 | 120 | 120 |
| Bunch population, $N$ | $[\times 10^{9}]$ | 1.0 | 1.0 | 1.0 |
| Beam-beam parameter per IR, $\xi$ | | .0016 | .0016 | $.004^{*}$ |
| Angular beam size, $\sigma'^{*}$ | $[\mu rad]$ | 108 | 153 | 95 |
| RMS beam size, $\sigma^{*}$ | $[\mu m]$ | 216 | 150 | 95 |
| Peak Luminosity, $L_0$ | $[10^{27} cm^{-2} s^{-1}]$ | 0.8 | 3.2 | 8.3 |
| Average Luminosity, $\langle L \rangle$ | $[10^{27} cm^{-2} s^{-1}]$ | $0.2^{\dagger}$ | $0.8^{\dagger}$ | $7^{\ddagger}$ |

$^{*}$RHIC II assumes electron cooling to reduce the emittance and counteract IBS.
$^{\dagger}$ Luminosity average over 10 hr for RMD and RDM+.
$^{\ddagger}$ Luminosity average over 5 hr for RHIC II since burn-off is high.

BROOKHAVEN NATIONAL LABORATORY

Waldo MacKay
RHIC Upgrades: 8 Dec., 2000

6

## Parameters for Proton Collisions

| Scheme | | RDM | RDM+ | RHIC II |
|---|---|---|---|---|
| Emittance (95%), $\epsilon$ | $[\pi\mu m]$ | 20 | 20 | $12^{*}$ |
| IP beta function, $\beta^{*}$ | [m] | 2.0 | 1.0 | 1.0 |
| Number of bunches, $M$ | | 60 | 120 | 120 |
| Bunch population, $N$ | $[10^{11}]$ | 1.0 | 2.0 | 2.0 |
| Beam-beam parameter per IR, $\xi$ | | .0037 | $.0073^{\dagger}$ | $.012^{\ddagger}$ |
| Angular beam size, $\sigma'^{*}$ | $[\mu rad]$ | 79 | 112 | 86 |
| RMS beam size, $\sigma^{*}$ | $[\mu m]$ | 158 | 112 | 86 |
| Peak Luminosity, $L_0$ | $[10^{31} cm^{-2} s^{-1}]$ | 1.5 | 24 | 40 |

$^{*}$ For RHIC II assumes electron cooling at injection to reduce emittance.
$^{\dagger}$ For RDM+ assumes only collisions at 3 IR's.
$^{\ddagger}$ For RHIC II assumes only collisions at 2 IR's.

# Rate Issues for TPC

Au-Au L ~ $8 \times 10^{27}\ cm^{-2}s^{-1}$
O-O L ~ $1.6 \times 10^{29}\ cm^{-2}s^{-1}$
p-p L ~ $2 \times 10^{32}\ cm^{-2}s^{-1}$
(possibly -> $4 \times 10^{33}\ cm^{-2}s^{-1}$)

## Track density in HI

$dN_{ch}/dy$ = 150 (min bias)
$L \times \sigma = 8 \times 10^{27} \times 7.2$ b
= 58 kHz

58kHz x 150 trks x 1.5
= $13 \times 10^{6}$ trks/sec
= 13 trks/$\mu$sec

## Track density in pp

$dN_{ch}/dy$ = 2.6
$L \times \sigma = 2 \times 10^{32} \times 60$ mb ($\sqrt{s}$ = 500 GeV)
= 12 MHz (min bias)

12 MHz => 12 events/$\mu$sec
=> ~50 m.b. events per drift time

12 MHz x 2.6 trks x 1.5 = $47 \times 10^{6}$ trks/sec
= ~ 47 trks/$\mu$sec

47 trks/$\mu$sec x 4 $\mu$sec = 188 trks
188 trks x 35 pts(max)/trk x 12 bytes/pt ~ 80 kB

# Data Volume and Readout Speed for TPC

## Number of channels

$A_{plane}$ = p ($55^2$ - $20^2$) = 8247 cm$^2$
$A_{pad}$ = 1.0 x 0.2 = 0.2 cm$^2$
$N_{pad}$ = 8247/0.2 = 41,233 x 2
= ~ 80K chs

## Data Volume

4 msec/20 ns => 200 time samples (8 bits)
80K x 200b ~ 16 Mb
Assume zero suppression of 1/20
=> 800 Kb
(actual hit rate gives 80 Kb => 1/200)

## Readout Speed in PHENIX

Buffer size < 40 beam clock ticks
40 x 100 ns (10 MHz) = 4 msec
(EMCAL pushes this to 6.4 msec)

Readout time < 40 msec (25 KHz in DCM)

800 Kb => 6.4 x $10^6$ bits/40 x $10^{-6}$ sec
= 1.6 x $10^{11}$ bits/sec
= 160 Gbits/sec (20 Gb/sec)
=> 160 1Gbit fibers (TEC has 128)
=> 40 DCMs (TEC has 28)

## Trigger

Expect actual trigger rate in pp to be ~$10^4$ Hz at L = 2 x $10^{32}$
(trigger rate of interesting events including W,Z,charm is only ~ $10^3$ Hz)
If data volume after final zero suppression is 80 Kb, then
80 Kb x $10^4$/sec => 800 Mb/sec
=> need Level 3 trigger

# Electronics Development

Investigate requirements for integrated TPC readout electronics

Assuming pad size of ~ 1.0 x 0.2 cm and an area of 0.8 $m^2$ per readout plane:

- 80K channels => 40K channels per readout plane (25 pads/$cm^2$)
- Power, cooling, services are a major design consideration

  assume 25 mW/ch => $4.0 \times 10^4$ x .025 = 1 kW/plane (not too bad!)
- Data volume is high (16 Mb unsuppressed) => need to do zero suppression in FEE
- Even with zero suppression, data transfer rate must be high

  160 Gbit/sec => 80 Gbit/side (2-8 Gbit G-links in the future ?)
- What will be the cost per channel ? ($40/ch?, STAR: $25/ch)
- Hopefully will save in cost/channel by doing highly integrated design

  (but then need good estimate of design costs)

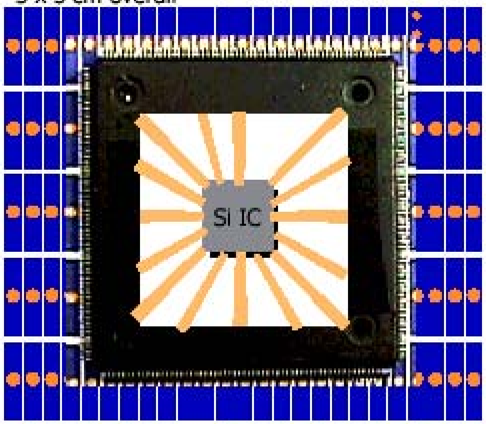
Readout requirements for HBD will be different than TPC

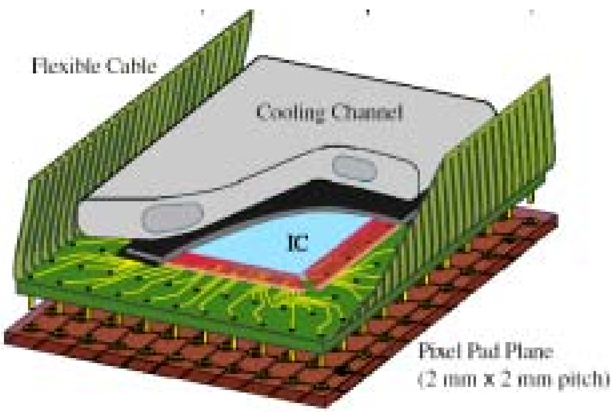
- May need to operate at higher gain
- Channel count will be lower (depending on segmentation)
- Electronics will be in the PHENIX acceptance => low mass

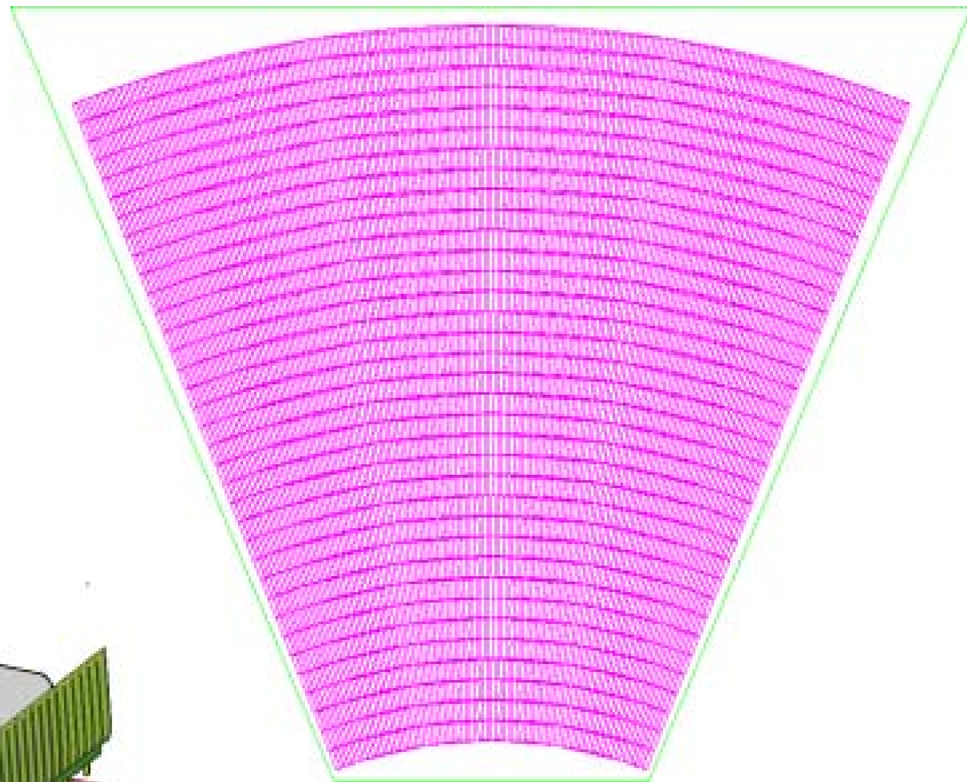
Readout must function in the existing PHENIX system readout architecture

- Buffer size < 4.0(6.4) msec (5 event buffer)
- Readout speed of 40 MHz (40 words/msec)
- Readout time < 40 msec (DCM speed = 25kHz)
- High luminosity pp running probably requires a level 3 trigger

# TPC Readout Plane and Electonics



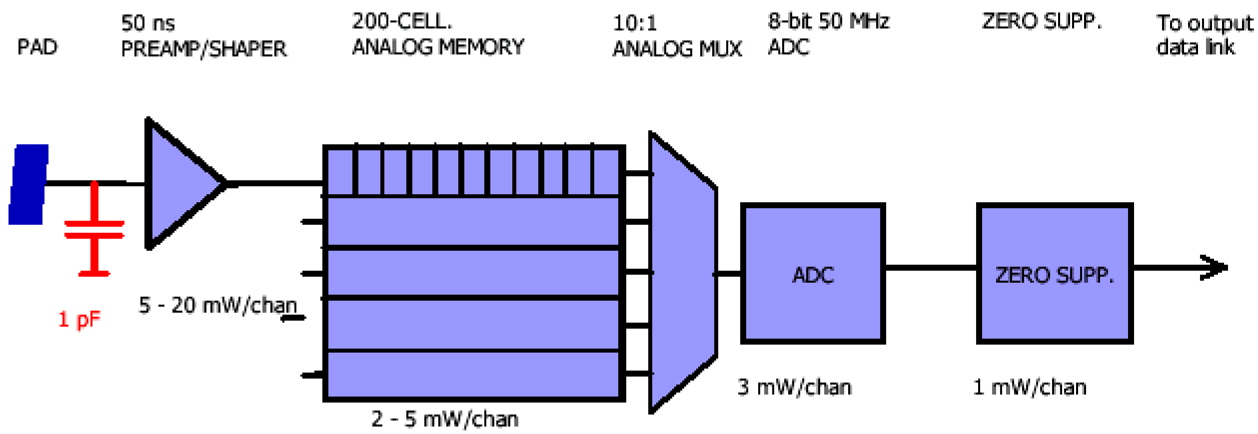



P.O'Connor
&
C.-Y. Chi

Readout Pads
DR ~ 1 cm
f ~ 2 mm

Segmentation driven largely by resolution

# Possible TPC Readout Electronics Chain




P. O'Connor

# Cost and Schedule Estimate

## R&D (2 years)

- HBD Detector Design: $250K
- TPC Detector Design: $500K
- Electronic Design: $1M (5 FTEs x 2 yrs)

Total: $1.75M

## Construction (2 years)

- Detector: $100K
- Gas System: $100 K
- Detector mounted electronics: $3.2M
  (80K Readout Channels @ $40/ch)
- Other readout electronics: $300K

Total: $3.7 M

### LEGS TPC

- R = 35 cm
- L = 60 cm
  (Single ended readout)
- 7K Readout Channels
- $CF_4$ gas

Total Cost ~ $0.5 M
Detector Cost : $50 K
Gas System: $50 K